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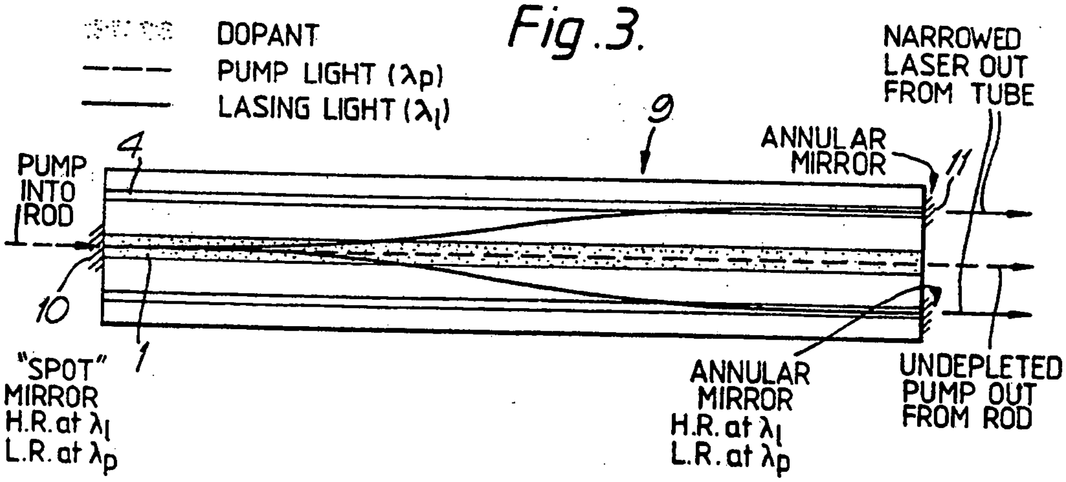
(54) Optical resonating device

(57) A line narrowing optical resonating device comprises a resonating cavity defined by a coaxial fibre (9) having a central rod portion (1) surrounded by a tubular portion (4) of high refractive index material. One end of the rod portion (1) is coated with a mirror (10) while the opposite end of the tubular portion (4) is coated with an annular mirror (11). One of the rod portion (1) and tubular portion (4) is doped with a lasing medium such as neodymium. The length of the coaxial fibre (9) is chosen such that optical signals at the lasing wavelength will couple between the rod portion (1) and the tubular portion (4) whereby signals at the lasing wavelength will oscillate within the coaxial fibre (9).

Fig.3.



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The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

Fig. 1A.

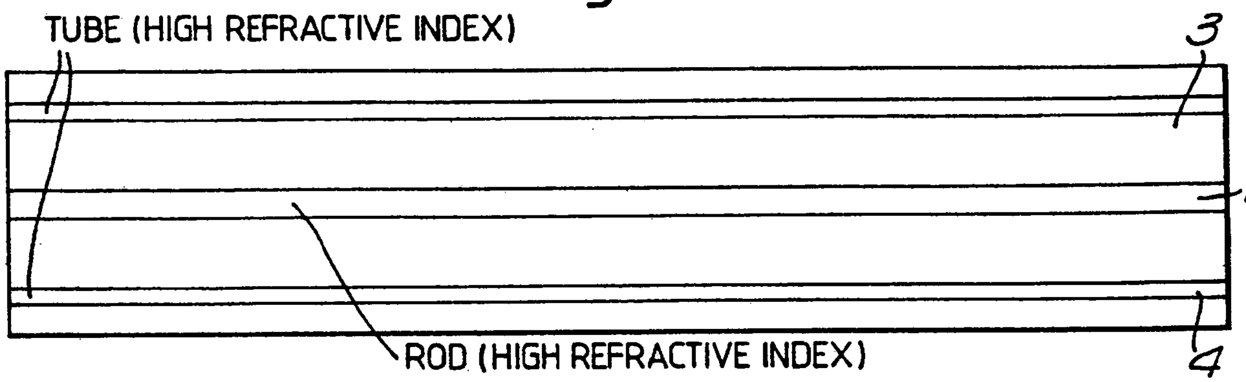


Fig. 1B.

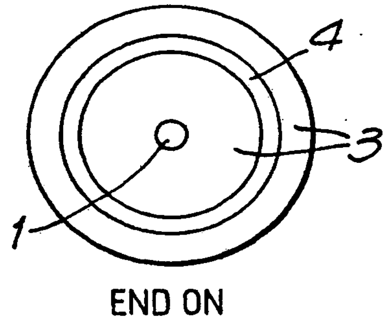


Fig. 1C.

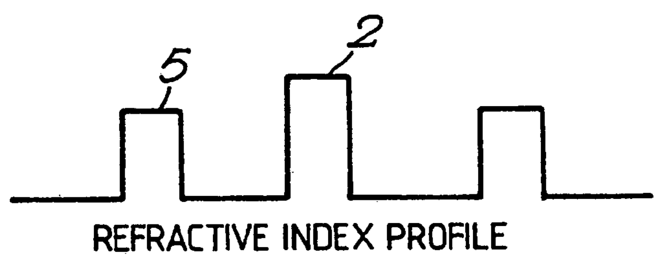


Fig. 2.

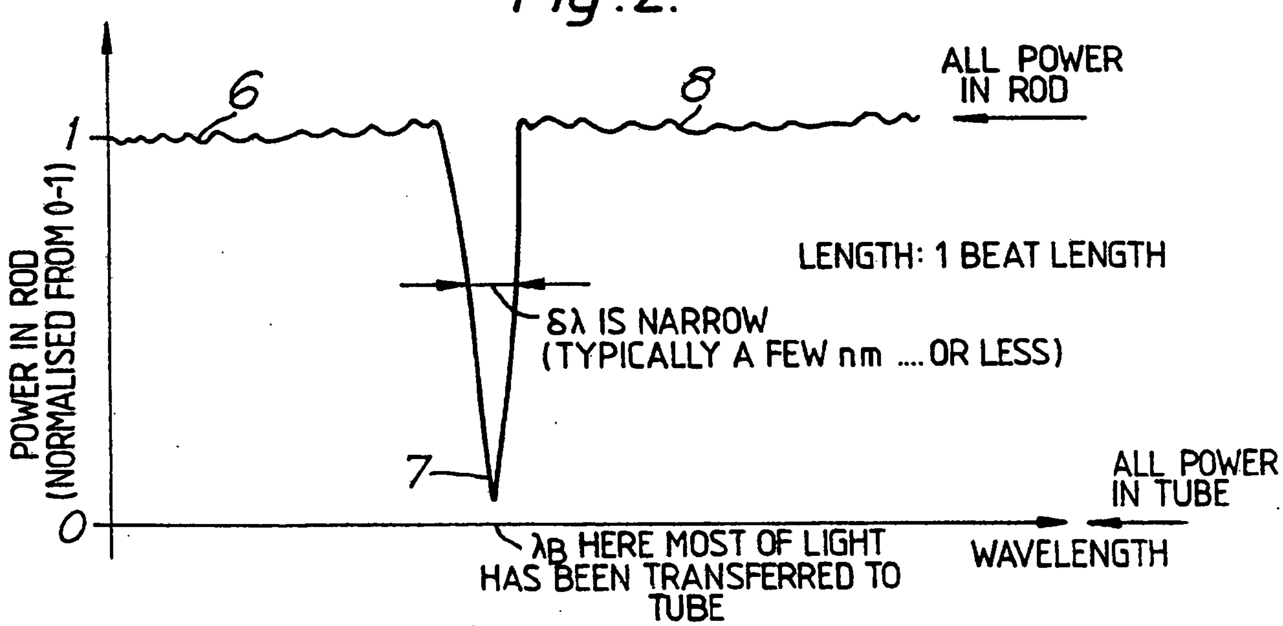


Fig.3.

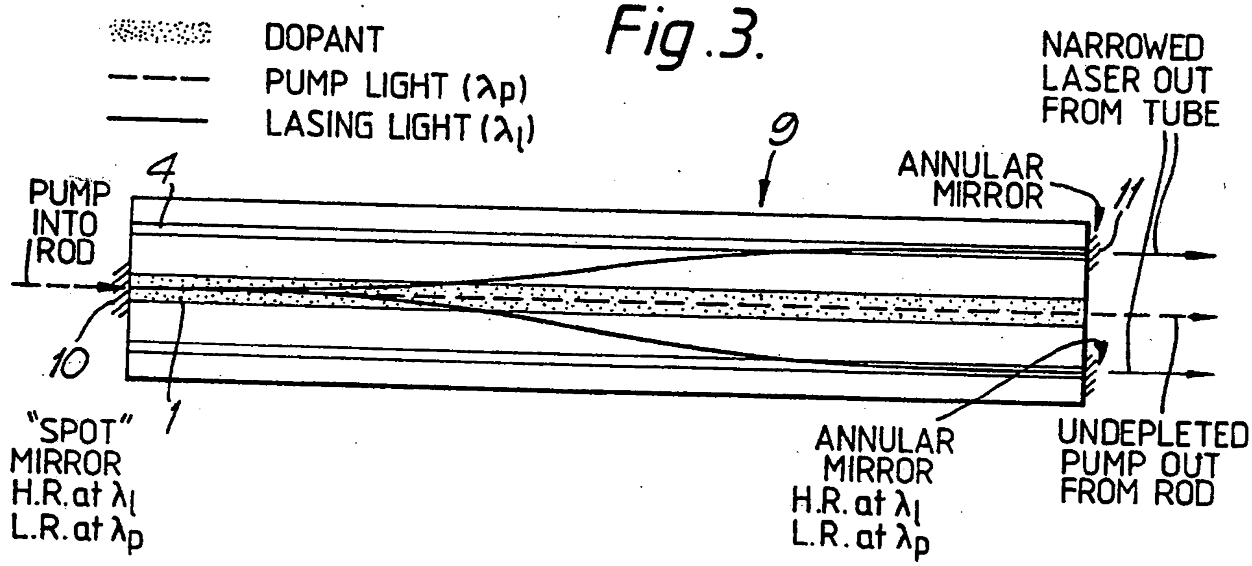


Fig.4.

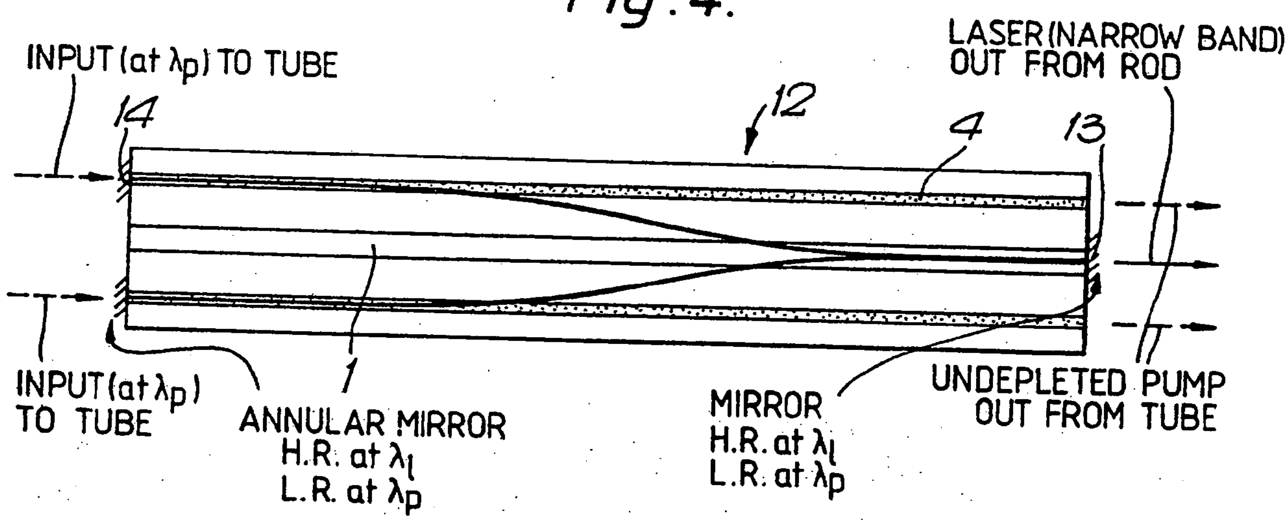
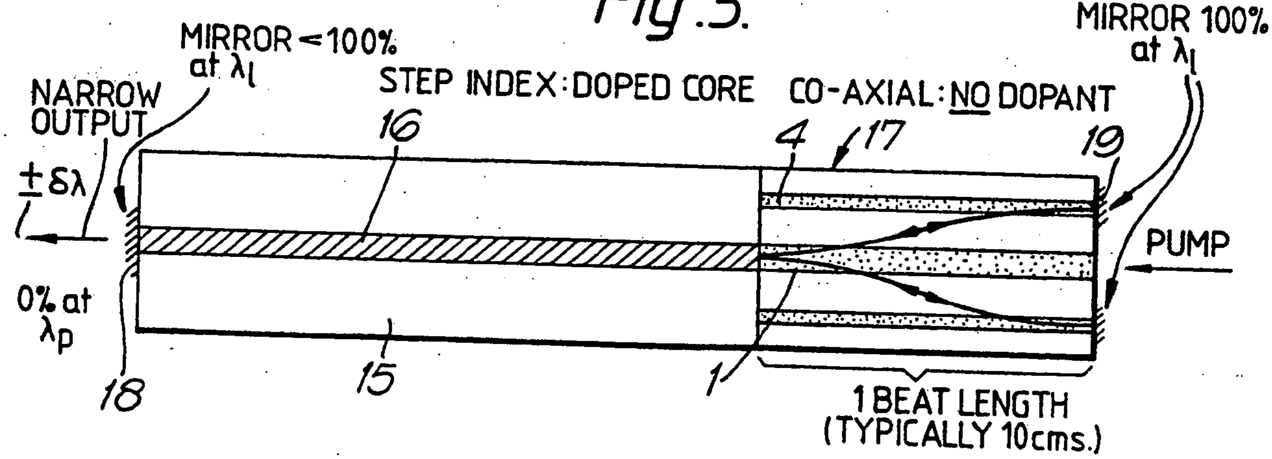


Fig.5.



OPTICAL RESONATING DEVICE

The invention relates to an optical resonating device for example for use as a laser.

One of the major problems with optical resonating devices such as lasers is the need for accurate alignment of the various components defining the optical cavity to enable maximum powers to be achieved at the oscillating wavelength.

In accordance with the present invention an optical resonating device comprises a resonating cavity defined by reflection means adapted to cause oscillation of signals in a predetermined wavelength band within the resonating cavity, at least part of the cavity comprising an optical waveguide assembly having a pair of waveguides, the waveguide assembly being adapted to couple optical signals in the predetermined wavelength band between the waveguides, and an optical amplification medium which emits radiation in the predetermined wavelength band.

This invention provides an optical resonating device which may be fabricated (possibly in a monolithic manner) from optical waveguide components leading to a general simplification in the overall structure with a reduction in the requirement for accurate alignment. In addition, the integrated design of the device results in lower losses and hence a lower oscillating threshold. The pair of waveguides can be selected by a suitable choice of dimensions and refractive indices of the constituent parts to achieve power transfer by coupling from one waveguide to the other at a narrow band of wavelengths. The pair of waveguides thus act as a filter. This is used as a convenient way to separate the pump and oscillating wavelengths, and to achieve line narrowing of the oscillating wavelength within the optical cavity.

In one example, one of the waveguides of the waveguide assembly may itself partially provide the optical amplification medium. For example the medium could comprise a lasing medium which emits radiation by stimulated emission, but other media which provide gain by parametric amplification, Raman scattering or Brillouin scattering may also be used. This provides a particularly compact arrangement. For example, the waveguide could be silica doped with neodymium which lases at about 0.9µm, 1.06-1.08µm, and about 1.34µm, erbium which lases at about 1.54 µm, prysodymium which lases at about 1.06µm, or even uranium.

In another example, the device may further comprise an additional optical waveguide which at least partially provides the optical amplification medium, the additional optical waveguide being coupled with the optical waveguide assembly to receive optical signals in the predetermined wavelength band from the optical waveguide assembly. The advantage of this is that it removes possible problems of transverse field overlap which could occur in the previous example where transverse fields do not overlap as well as if they were both confined to the same portion of the waveguide. The difficulty with having a poor transverse field overlap is that the lasing threshold power is increased and the slope efficiency is reduced. For example, the additional optical waveguide may comprise a step index optical fibre spliced to the optical waveguide assembly.

The optical waveguide assembly may comprise two parallel optical waveguides spaced apart within a suitable supporting medium. Preferably, though, the optical waveguide assembly comprises a pair of nested waveguides, for example coaxial optical fibres. Typically, these may be a rod shaped optical fibre

surrounded by a tubular optical fibre within a suitable supporting material.

Preferably, the optical waveguide assembly has a length substantially equal to an odd integral number of beat lengths, as hereinafter defined.

In this context, a "beat length" is defined as being the minimum length of an optical waveguide assembly necessary for there to be substantially complete power transfer from one optical waveguide to the other for signals within the predetermined wavelength band.

This requirement is particularly important where one of the components of the optical waveguide itself comprises the optical amplification medium. In the example where an additional waveguide is provided, the beat length of the optical waveguide assembly need only be chosen to be long enough to obtain suitable narrow filtering.

Typically, the reflection means will comprise suitable dielectric reflective materials coated onto the optical waveguide assembly and/or additional optical waveguide. However, alternative forms of reflection means such as Bragg gratings or looped optical waveguides connected to directional X couplers could also be used.

Power input to the device may be achieved by injecting optical signals at pump wavelengths through one of the reflection means which is thus conveniently transmissive to signals at the pump wavelengths. Alternatively, the optical power could be launched into the cavity via some other form of optical coupling means associated with the optical waveguide assembly. For example, this could be achieved by positioning an additional optical waveguide adjacent to the optical waveguide assembly such that transfer of optical power at the pump wavelength occurs between them.

Preferably, the optical fibres used are monomode optical fibres although in some applications multimode optical fibres may also be acceptable.

In this specification, the term optical is intended to refer to that part of the electro-magnetic spectrum which is generally known as the visible region together with those parts of the infra-red and ultra-violet regions at each end of the visible region which are capable of being transmitted by dielectric optical waveguides such as optical fibres. At present, wavelengths up to about 1.57μm (infra-red) are envisaged but this could extend into the mid infra-red region with wavelengths of up to 5μm or beyond.

Some examples of optical resonating devices according to the invention will now be described with reference to the accompanying drawings, in which:-

Figures 1A - 1C are a schematic longitudinal section, an end view, and a graphical illustration of the variation in refractive index respectively of a coaxial optical fibre;

Figure 2 is a graphical illustration of the variation in power distribution for a coaxial fibre with wavelength for a coaxial fibre; and,

Figures 3, 4, and 5 are schematic, longitudinal sections through three examples of optical resonating devices.

A conventional coaxial optical fibre comprises a rod shaped optical fibre 1 having a relatively high refractive index 2 (Figure 1C) within a material 3 with a relatively low refractive index. Surrounding the rod 1 and coaxial with it is a tubular optical fibre 4 having a refractive index which is relatively high compared with the supporting material 3 but which is slightly lower than the refractive index of the rod 1. The refractive index of the tube 4 is indicated at 5 in Figure 1C.

The response of a coaxial optical fibre of the type shown in Figure 1 to radiation injected through one or other of the rod 1 and tube 4 is schematically illustrated in Figure 2. This indicates graphically the distribution in optical power between the tube 4 and the rod 1 for a variety of wavelengths. Thus, it is assumed that optical signals are injected into the coaxial fibre through the rod 1. At low wavelengths, as indicated by the portion 6 of the graph shown in Figure 2, substantially all optical power remains within the rod 1. As the wavelength is increased, a particular wavelength, λ_B is reached at which substantially all the optical power is coupled from the rod 1 to the tube 4 as indicated at 7. In practice, a small band of wavelengths centred on λ_B will be coupled between the rod and the tube, the bandwidth typically being about a nm or less. At wavelengths above λ_B coupling ceases and power remains within the rod 1 as indicated at 8. The wavelength λ_B at which transfer between the rod and the tube occurs depends upon the dimensions and refractive indices of the constituent parts of the coaxial fibre but for any coaxial fibre in which the refractive indices are fixed, this transfer will depend upon the length of the coaxial fibre. The length of coaxial fibre required to cause optical signals at a particular wavelength to be coupled between the rod and the tube is known as the "beat length". In practice, coupling of this "predetermined wavelength" will occur in coaxial optical fibres which have lengths which are odd integral multiples of the beat length.

The effect of this property is that the coaxial fibre acts as a filter and this property is used in the optical devices to be described below.

Figure 3 illustrates a first example in which a laser cavity is defined by a coaxial optical fibre 9 of

the type shown in Figure 1A having a tube 4 and rod 1. In this example, a spot mirror 10 is deposited on the end of the rod 1 while an annular mirror 11 is deposited on the opposite end of the tube 4. The spot mirror 10 has a low reflectivity at the wavelength λ_P of a pump power source (not shown) to enable optical pump signals to be injected into the rod 1. Both the mirrors 10, 11 are highly reflective at the lasing wavelengths (λ_L).

The rod 1 is doped with some ionic species such as neodymium for which a suitable pumping wavelength (λ_P) is 800-810μm corresponding to the range of available outputs from GaAs semiconductor diode lasers. The pump signals will cause the lasing medium within the rod 1 to fluoresce over a broad band of wavelengths. In a single core fibre laser lasing would then occur over a narrow band of wavelengths within the broad band fluorescence profile, centred on the lasing wavelength (λ_L). But by using the coaxial fibre 9 and by choosing the length of the coaxial fibre 9 to be substantially equal to the beat length for the lasing wavelength, lasing occurs only over a very narrow band of wavelengths within the original lasing profile, centred on the lasing wavelength (λ_L), the lasing signal being coupled into the tube 4 while all other wavelengths (including the pump and background) remain within the rod 1 and pass out of the coaxial fibre at the far end. The lasing wavelength signals however are reflected by the mirrors 10, 11 and thus oscillate within the coaxial fibre 9.

The lasing signals can be output via the tube mirror 11, travelling forward, or via the rod mirror 10, travelling backwards with respect to the pump. In the latter case, the tube mirror 11 should be 100% reflective at the lasing wavelength for greatest efficiency and the spot mirror less than 100%. In that case, a beam

splitter will be required at the input end to separate the lasing wavelength from the incoming pump signal.

Figure 4 illustrates an optical device similar to that shown in Figure 3 but acting in the reverse sense. In this case, a coaxial optical fibre 12 is provided in which the tube 4 is doped with the lasing medium while the rod 1 is undoped. A spot mirror 13 is coated onto one end of the rod 1 and is selected to be highly reflective at the lasing wavelength but to have low reflectivity at the pump wavelength. An annular mirror 14 is coated onto the opposite end of the tube 4 and is chosen to have high reflectivity at the lasing wavelength and to have low reflectivity at the pump wavelength.

The pump light (λ_p) is launched into the tube 4 through the annular mirror 14 causing the medium within the tube 4 to lase. The lasing wavelength is coupled into the rod 1 and then caused to oscillate between the mirrors 13, 14. Other wavelengths including the pump and spontaneous background signals pass uncoupled to the tube 4 and out at the far end. The laser output is taken through the spot mirror 13.

One possible problem with the Figure 3 and 4 examples is that transverse field overlap may not be optimum. Thus, the pump signal remains in the waveguide into which it was first launched whilst during the course of a transit of the fibre, the narrow bandwidth of light at the lasing wavelength was transferred between the rod and the tube. The transverse fields do not overlap as well as if they were both confined to the same portion of waveguide.

The example shown in Figure 5 is designed to overcome this problem. In this example, a step index optical fibre 15 having a high refractive index rod portion 16 is spliced to a coaxial fibre 17. The coaxial fibre 17 is not doped and simply serves as a wavelength

filter while the rod portion 16 of the optical fibre 15 is doped with a lasing medium. The gain and hence the wavelength conversion takes place in the core of the doped step index fibre 16. A mirror 18, which can be either a spot mirror or a bulk mirror, is provided on one end of the rod portion 16 of the optical fibre 15 while an annular mirror 19 is provided on the remote end of the tube 4 of the coaxial fibre 17. The mirror 19 is chosen to be 100% reflective at the lasing wavelength λ_L while the mirror 18 is slightly less than totally reflecting at the lasing wavelength. Pump signals are launched into the rod portion 1 of the coaxial fibre 17 causing the lasing medium within the rod portion 16 of the optical fibre 15 to generate optical signals at the lasing wavelength. The lasing wavelength signals are substantially completely reflected back along the rod portion 16 to the rod 1. Within the coaxial fibre 17, the lasing wavelength signals are coupled into the tube 4 and are totally reflected at the mirror 19 back into the rod portion 16. Thus, oscillation at the lasing wavelength occurs between the mirrors 18, 19. The laser output is taken through the mirror 18 although it could be taken in a contra-directional manner with respect to the pump although the former has the advantage of coupling out of the system via a core waveguide. The step index fibre 15 can be as long as necessary for the purpose of obtaining sufficient gain to initiate lasing at a low power level. The beat length of the coaxial fibre 17 need only be chosen to be long enough to obtain suitable narrow filtering. Typically, one beat length will be in the order of 10cms.

CLAIMS

1. An optical resonating device comprising a resonating cavity defined by reflection means adapted to cause oscillation of signals in a predetermined wavelength band within the resonating cavity, at least part of the cavity comprising an optical waveguide assembly having a pair of nested waveguides, the waveguide assembly being adapted to couple optical signals in the predetermined wavelength band between the waveguides, and an optical amplification medium which emits radiation in the predetermined wavelength band.

2. A device according to claim 1, wherein the optical amplification medium comprises a lasing medium.

3. A device according to claim 1 or claim 2, wherein the optical waveguide assembly comprises a pair of nested waveguides.

4. A device according to claim 1 or claim 2, wherein one of the waveguides of the waveguide assembly at least partly provides the optical amplification medium.

5. A device according to any of the preceding claims, further comprising an additional optical waveguide which at least partly provides the optical amplification medium, the additional optical waveguide being coupled with the optical waveguide assembly to receive optical signals in the predetermined wavelength band from the optical waveguide assembly.

6. A device according to claim 5, wherein the additional optical waveguide comprises a step index optical fibre.

7. A device according to any of the preceding claims, wherein the optical waveguide assembly comprises coaxial optical fibres.

8. A device according to any any of the preceding claims, wherein the optical waveguide assembly has a

length substantially equal to an odd integral number of beat lengths, as hereinbefore defined.

9. A device according to any of the preceding claims, wherein at least one of the reflection means is transmissive to signals at pump wavelengths.

10. An optical resonating device substantially as hereinbefore described with reference to any of the examples illustrated in the accompanying drawings.

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